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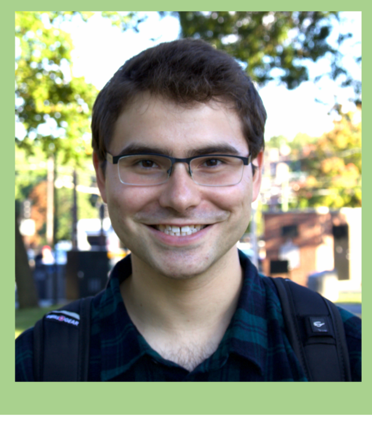

A Nature-Inspired Passive Airflow System for Carbon Capture and Sequestration

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Background

Carbon capture and sequestration (CCS), where carbon dioxide (CO_2) is removed from the air and stored so it cannot return to the atmosphere, can reduce the impacts of climate change. However, CCS systems are unpopular due to their high energetic and financial costs [1]. Although half of global emissions, produced by sources such as transportation, can only be removed through direct air capture (DAC), to-date few DAC systems exist [2]. To address the issue of high energetic cost, and provide another option for ambient air CCS, a passive airflow system was developed. This system replaces the energetic input used to bring CO_2 into DAC systems from devices such as electric fans. The design shown is a proof of concept that uses passive airflow and a solution of Mg^{2+} ions and carbonic anhydrase (CA) enzyme to sequester CO_2 as solid carbonate, $MgCO_3$.

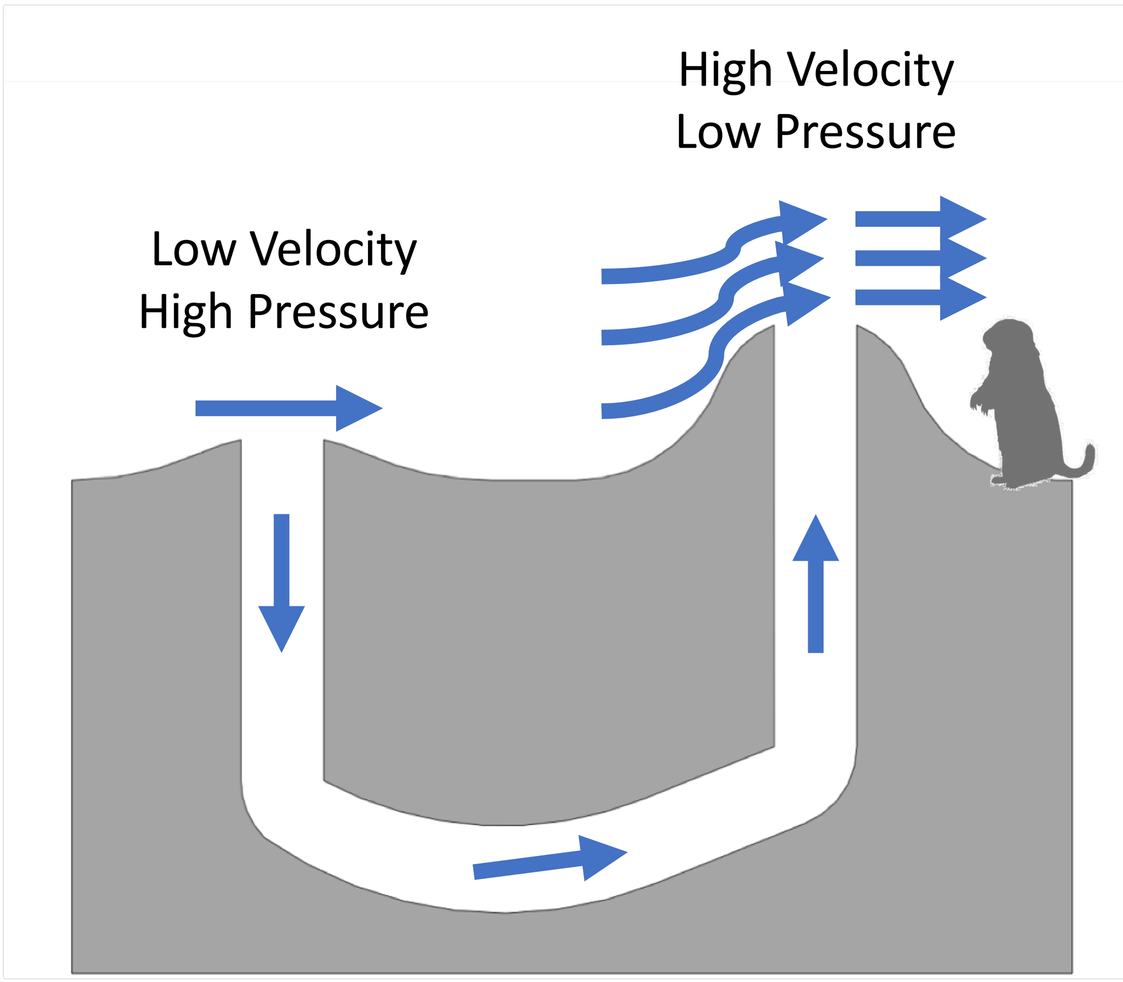


Figure 1: Passive Airflow in Prairie Dog Burrows

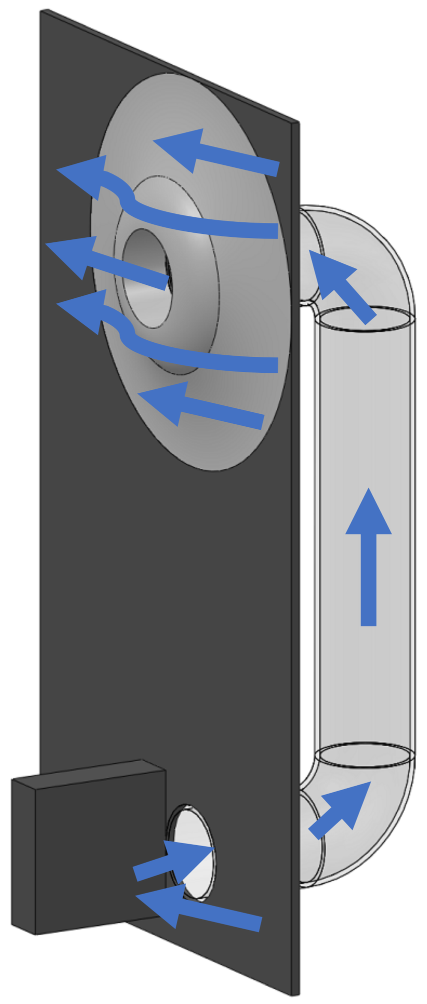


Figure 2: Reactor Passive Airflow System

Nature-Inspired Passive Airflow

Passive airflow method inspired by prairie dog burrows (figure 1)

- Wind accelerates over tall mound reducing its pressure relative to air over short mound
- Pressure difference forces air to move through the burrow [3]

Reactor's passive airflow system mimics prairie dog burrow rotated 90˚ (figure 2)

- One mound used to maximize height and resulting pressure difference
- Mound placement forces air to move upwards, countercurrent to solution for effective CO_2 capture [2]
- Block behind inlet forces additional air inside by reducing wind velocity

Reaction Used

$$Mg^{2+}_{(aq)} + CO_{3\,(aq)}^{2-} \rightarrow MgCO_{3\,(s)}$$

- 18 gigatons per year (Gt/yr) of waste water rich in Mg^{2+} ions produced by the oil industry could capture 0.84 Gt/yr of CO_2 (2% of the emissions released in 2017) [4,5]
- CA enzymes used to accelerate slow conversion of CO_2 to HCO_3^-, which becomes CO_3^{2-} in pH 10 solution [4]

Reactor Description

- Nature-inspired airflow system passively flows wind containing CO_2 up a column while solution flows down internal surface area (or packing)
- Mg^{2+} ions and carbonic anhydrase enzymes in solution capture and sequester CO_2 as $MgCO_3$
- Solid $MgCO_3$ captured as solution is vacuumed through filter paper
- Pump cycles solution for additional capture

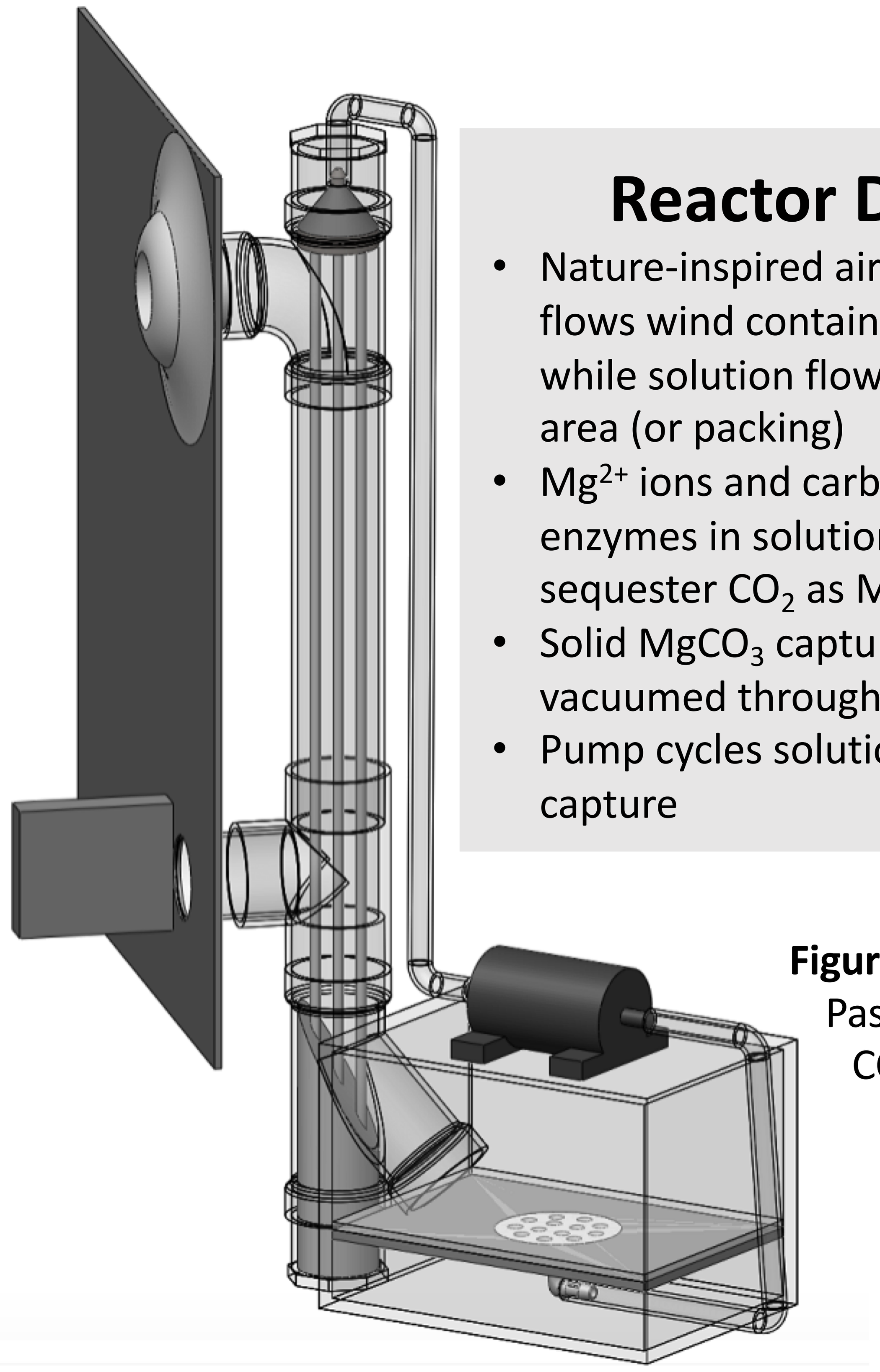


Figure 3: Complete Passive Airflow CCS Reactor

Testing

Effect of Liquid Flow Rate on Passive Airflow

- Used distilled water at flow rates from 0 to 4 L/min
- Simulated "wind" at relatively constant velocity with electric fans
- Fan anemometer measured "wind" velocity and thin hot wire anemometer inside system measured passive air velocity

CO_2 Sequestration Tests

- Solution containing 0.0625M $Mg(OH)_2$ and 20mg/ 100mL CA enzyme used at flow rates from 1 to 3 L/min
- Attempted to keep "wind" velocity consistent for each test
- Precipitates were collected, massed, and analyzed with x-ray diffraction to determine fraction of $MgCO_3$ produced from $Mg(OH)_2$

Results

Effect of Liquid Flow Rate on Passive Airflow

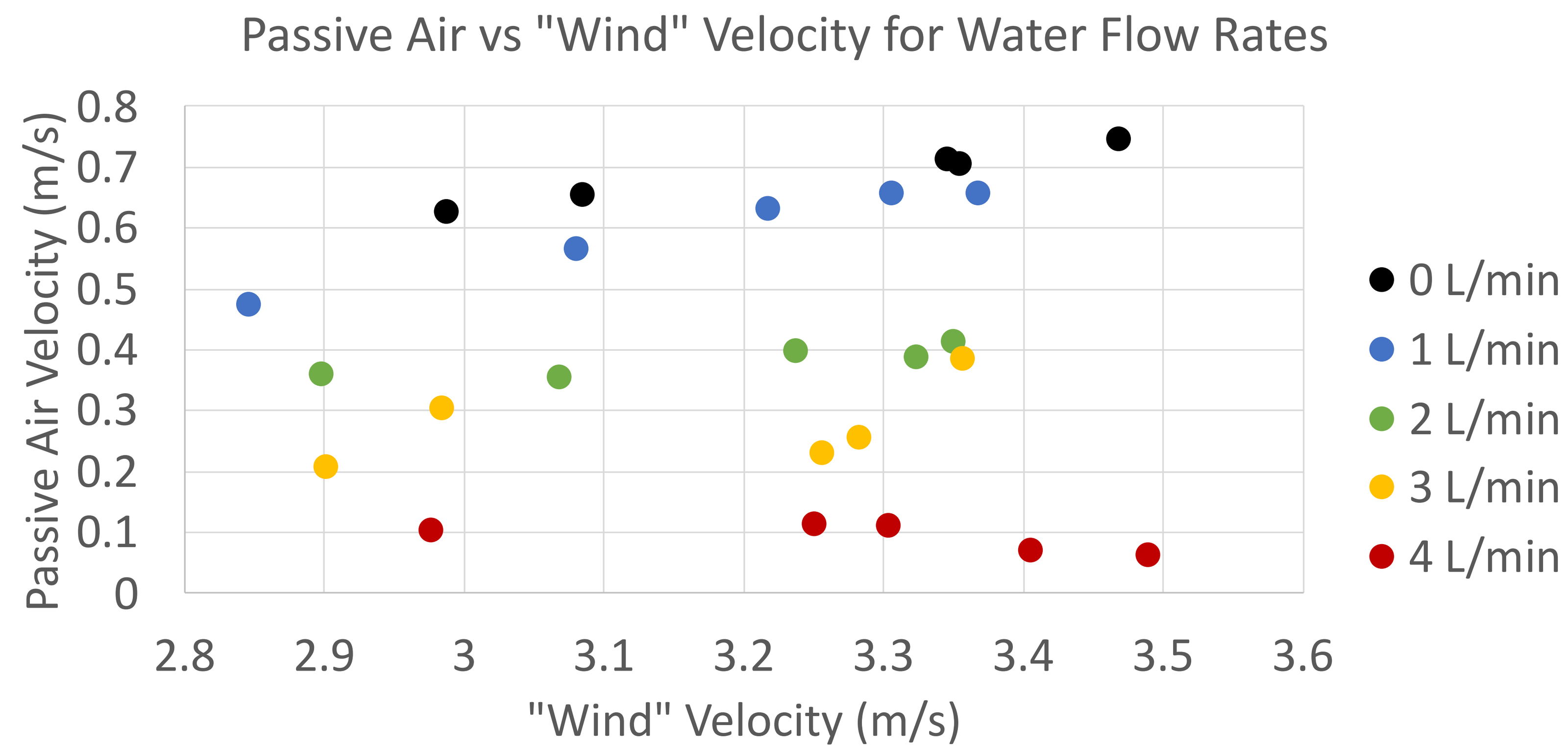
- Increasing water flow rate reduced passive air velocity (graph)
- But in reaction tests, 2 L/min rate had highest passive air velocity (table)
- Discrepancies likely due to inconsistent "wind" velocities from fans

CO_2 Sequestration Tests

- Reaction rates were similar, potentially unaffected by solution flow rate
- Increasing solution flow rate likely does not improve efficiency of sequestering CO_2, since 1 L/min flow rate had lowest energy cost

Calculations

- Reaction rate: divided moles of $MgCO_3$ produced (estimated due to precipitates trapped in filter paper) by duration of tests (varied due to solution evaporating) and volume of solution used
- Energy cost: divided energy input by mass of CO_2 sequestered
- Lowest realistic energy cost: used potential energy to move solution to top of system multiplied by efficiency of commercial pump, 84% [6]



Flow Rate (L/min)	Wind Velocity (m/s)	Passive Air Velocity (m/s)	% $MgCO_3$ (3 H_2O)	% $Mg(OH)_2$ Remaining	Estimated Reaction Rate (M/hr)	Lowest Realistic Energy Cost (kWh/ ton of CO_2)
1	3.57	0.36	90.3%	9.7%	1.51×10^{-2}	420
2	3.33	0.38	97.4%	2.6%	1.34×10^{-2}	906
3	2.84	0.27	98.5%	1.5%	1.79×10^{-2}	1,209

Discussion

Passive airflow enabled ambient air CCS. The current system, with an efficient pump, could be a competitive method of CCS. While other carbonate producing methods such as ultramafic reactors have energy costs from 430 to 2400 kWh/ ton of CO_2, this system could require 420 kWh/ ton of CO_2 [7]. However, passive airflow must be enabled for large reactors with high internal surface areas to capture enough CO_2 to affect climate change and ensure lower financial costs when scaled-up. In future tests, an air tunnel can be used for consistent "wind" speeds.

Sources

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